Core Concepts
• Despite development of guarded filtration surgery (GFS) into modern trabeculectomy over the last 40 years, current methods still lack efficiency, high success rates and long-term stability.
• The best organised and well known approach to trabeculectomy is the Moorfields safe surgery system (MSSS).
• Mitomycin C (MMC) improves post trabeculectomy IOP control significantly, but is also associated with bleb leaks or long-term hypotony. The latter issues may be minimized with appropriate surgical technique.
• Pre-surgical treatment with MMC to decrease ocular surface inflammation may decrease risk of failure by scarring.
• The Express implant effectively stents the sclerotomy, but further studies are needed to demonstrate long-term efficacy and safety.
• The 3 year data of the Tube vs. Trabeculectomy study fulfilled expectations, demonstrating a 31% chance of failure in the trabeculectomy group.
• Bleb morphology needs to be optimized, diffuse blebs are desirable. The new Moorfields system is useful for adequately grading blebs.
• Non-penetrating glaucoma surgery (NPGS) approaches have decreased complication rates, but also yield less IOP-lowering effects. YAG laser gonipuncture may be needed to create a sclerotomy.
• In the last 10 years trabeculectomy success and complication rates have improved significantly due to a better understanding of functional components of the surgery as well as management of wound healing.

Introduction
Despite serial improvements over the guarded filtration surgery (GFS) described by Cairns and Watson1-4 that has evolved into modern trabeculectomy, GFS still lacks the efficiency, high success rates, and long-term stability expected from, for example, cataract surgery. Incremental gains particularly in the peri-operative period mean increased safety with refinements such as releasable or adjustable sutures, anti-metabolites and improved understanding of pre-existing risk factors for failure.

Modern trabeculectomy is different enough from Cairns and Watson’s original description, hence even the name itself is a misnomer; usually no trabeculum is excised. But the core advance of the Watson and Cairns trabeculectomy, the message of ‘control outflow to improve the safety of the procedure’, became neglected frequently enough in later years as postoperative flat anterior chambers, choroidal detachments, and hypotony maculopathy came to be expected, and many authors published results showing that the control of IOP after surgery was less than ideal.

Multiple non-trabeculectomy surgical techniques and variations on these have also been published, usually as case series compared with trabeculectomy, and typically the newer procedure outperformed a fairly lacklustre set of trabeculectomy outcomes. So far, few of these alternative approaches have been able to match the efficiency, effectiveness and economy of a well-performed and managed trabeculectomy. Recently the Tube vs. Trab study5 demonstrated similar short-term efficacy and safety of these two procedures, with long term results awaited.

While trabeculectomy might be very simple in concept, performing it well and consistently requires fastidious attention to detail and a deep understanding of how components of the procedure interact. New approaches to trabeculectomy with close attention to underlying principles of aqueous dynamics and tissue responses were developed; currently the best organised and well known of these is the Moorfields safe surgery system (MSSS), although many individual surgeons, having grasped the ideas behind MSSS, have developed their own modifications.

Technical advances in trabeculectomy

Anti-scarring agents
Mitomycin C (MMC) in particular improves post trabeculectomy IOP control significantly, but also amplifies imperfections in surgical technique, increases the risks of complications such as bleb leaks, bleb-related endophthalmitis, and long-term hypotony with secondary consequences. While MMC is blamed for these complications, they were common after full-thickness surgery that predated antimetabolites; they may be minimized with appropriate surgical technique.

MMC may be safer for operating room staff and patients if it is stained with trypan blue or indocyanine green (Figure 1), with no adverse effects6,7

Preparation and Conjunctival Approach
When MMC became more common in GFS, increased conjunctival wound leaks led to a change from fornix- to limbus-based conjunctival flaps. As better bleb morphology is more likely after a fornix-based approach6,9 conjunctival incisions are more popular at the limbus. While wound leaks in the early postoperative period are detected more commonly with limbal incisions, small early wound leaks have a minor influence on long term surgical outcome8,10. A fornix-based inci-

The superior limbus is the preferred site to insert the bleb; it provides a wide surface that helps to direct aqueous flow posteriorly. Confrontation with a corneal traction suture offers better surgical visibility with easier access, hence a more precise scleral flap construction and suture placement. In the early post-surgical period the conjunctiva provides little resistance to flow and even a tight closure of the conjunctival wound will not prevent hypotony if the scleral parts of the operation are not well constructed. Pre-surgical treatment to decrease ocular surface inflammation may decrease risk of failure by scarring13. The superior limbus is the preferred site to minimize bleb exposure problems.

Scleral flap, Sclerostomy, and Sutures

It is the combination of the scleral flap and suture placement, in conjunction with the underlying sclerostomy that controls the early postoperative IOP. Simple measures with attention to detail, understanding scleral flap function, and carefully using adjustable/releasable sutures, early postoperative hypotony and flow-on complications can be minimized.

Major points to consider for scleral flap construction and suture placement:

- Resistance to outflow arises from scleral flap apposition over its bed and the sclerostomy edge, not the apposition of the flap edges to the scleral bed.
- Keep the sides of the scleral flap behind the posterior extent of the sclerostomy: flow control may be lost if side incisions are too anterior, and it helps to direct aqueous flow posteriorly.
- Avoid making the sclerostomy large relative to the scleral flap, to avoid full-thickness fistulas as the tissue remodels (Figure 2). Punches such as the Kelly or Khaw are best. Flap width should be wider (>0.5mm each side) than the sclerostomy.
- Using a crescent blade to create the scleral tunnel may facilitate consistent scleral flaps. Keep the antero-posterior extent of the central trapdoor < 2.5mm to decrease the chance of a flap that is too thin or too thick.
- Consider a W-shaped or modified trapezoidal flap (Figure 3). With increased resistance to lateral flow, posterior flow is maximized, and the short anterior dissection distance minimizes mistakes in scleral flap depth.

- Avoid making the sclerostomy too thin or too thick.
- Test scleral flap ability to limit flow before closing the conjunctiva: represent the difference in the distances that aqueous has to travel against resistance to reach the subconjunctival space, with the resulting aqueous flow represented by the grey arrows. The orange arrows show the position and force directions of adjustable sutures; in most cases only two are required.

Scleral flap, Sclerostomy, and Sutures

- Avoid full thickness flow through the trapdoor: a perforating blood vessel or suture hole in the flap overlying the sclerostomy will compromise scleral flap function.
- A suture that is both releasable and adjustable offers maximal control of immediate postoperative flow. (Figure 4). Four throws of 10-0 Ethilon are dependable and robust, and yet remain adjustable.
- Test scleral flap ability to limit flow before closing the conjunctiva: represent the anterior chamber to ensure adequate outflow resistance. Aim for day 1 IOP of approximately 20 via appropriate suture tightness and then consider lowering the IOP by adjusting the sutures.

Figure 1. Indocyanine green (ICG) (or trypan blue) can be mixed with Mitomycin C to show exactly where the MMC has gone, how large the treatment area is, and the location of any split antimetabolite; making the procedure safer for the patient and operating theatre staff. Trypan blue stain lasts for several hours. ICG is visible for a day or two after surgery.

Figure 2. Full thickness drainage at the edge of the scleral flap results from the edge of the sclerostomy being too close to the edge of the scleral flap. The appearance of an avascular (cystic) area overlying the full-thickness defect is characteristic, sometimes referred to as an ‘aqueous jet’, and was the typical appearance following the full-thickness glaucoma procedures that preceded guarded filtration surgery. Blebs like this typically weep and are associated with late hypotony and bleb-related endophthalmitis. To avoid this, ensure that the width of the scleral flap is much greater than that of the sclerostomy.

Figure 3. The W-shaped flap, outlined in orange, is the author’s preferred scleral flap construction. The smallest grey semicircle represents the sclerostomy made by a 0.5mm Khaw punch, and the blue arrows show the difference in the distances that aqueous has to travel against resistance to reach the subconjunctival space, with the resulting aqueous flow represented by the grey arrows. The orange arrows show the position and force directions of adjustable sutures; in most cases only two are required.

Figure 4. Adjustable suture placement in W-flap trabeculectomy. Left image: Sutures placed with corneal loops in peripheral corneal grooves allowing complete removal in case adjustment fails. Placing loops into corneal grooves ensures they are comfortable, and do not necessarily need to be removed if post-surgical progress is good. Loops above the trapdoor itself are in preparation for tying. Right image: the suture on the right is tight. Note the small loop of suture extending from the 4-throw knot which avoids the loop catching in tenons tissue if removal is desired. The left suture is being tightened. Holding the loop end tying forces along the line of the suture, and holding the free suture end across the line of the suture ensures that if it breaks, it is the free end that breaks first. This patient had Sturge-Weber Syndrome with a large choroidal haemangioma, the AC infusion (Lewicky cannula) ensured that control of the IOP and anterior chamber is not lost during the procedure. IOP on day 1 was 22mmHg, suture adjustment to 14mmHg on day 1 was followed by further adjustment to 12mmHg at week 2.
Suture adjustment:
Prior to healing and remodeling of the surgical site, delayed for many weeks by antimetabolites, suture tension determines scleral flap tension over the sclerostomy, which controls IOP. This tension, and therefore the IOP, can be controlled accurately in both laboratory models and in real patients (Figure 5)\(^\text{14,16}\). Suture adjustment is straightforward, and more reliable than either suture lysis/release or trapdoor massage. An aqueous gush may falsely reassure the patient and surgeon since it may take more than 30 minutes to re-establish equilibrium\(^\text{18}\).

Sclerostomy:
The sclerostomy needs to be > 50\(\mu\) wide\(^\text{18}\), which is 1/5\(^\text{th}\) the diameter, and 1/25\(^\text{th}\) of the area, of the smallest available punch. Iris or vitreous plugging follows loss of anterior chamber and bulk outflow of aqueous, which is more likely if the sclerostomy is large and prevents effective flap control of flow. To minimize intraoperative hemorrhage and ciliary body incarceration, the sclerostomy should be just anterior to the trabecular meshwork, in peripheral cornea.

Stenting the Sclerostomy:
The Ex-Press implant, initially developed as a full-thickness drainage implant, but now refined to be implanted under a scleral flap, effectively stents the plant, but now refined to be implanted as a full-thickness drainage implant. MRI. Further high-quality studies are awaited.

Safety and efficacy of modern trabeculectomy:
Trabeculectomy has evolved\(^\text{23}\) from having a “very high risk profile”, with “moderate long-term results at best”.\(^\text{24}\) Half the outcome follows what happens in the operating room and half relies on the peri-operative management.

Small series of trabeculectomies show low complication rates with good short and intermediate-term success rates; typical rates for flat anterior chambers, hyphema, and choroidal detachments reported <5% with IOP <18mmHg in up to 90% of cases at 3 years\(^\text{14,24,25}\). In a group audit\(^\text{26}\) of 428 modern trabeculectomies from 9 centers using several variations from the MSSS showed 7% transient hypotony, 5% hyphema, and 0.5% shallow anterior chambers. At 2 years 92% had IOPs of 21 or below on no IOP-lowering medications, and at a mean follow-up of 45 months median IOP was 12mmHg with 80% having IOPs of 18mmHg or less without medications. In the Tube vs. Trabeculectomy (TVT) study 3-year results\(^\text{4}\), the trabeculectomy group had an average of 1±1.5 medications, a 31% chance of failure, 60% complications, and 27% chance of complications severe enough to warrant reoperation or result in 2 lines or more of visual loss. Although one of the best surgical glaucoma studies ever published, the outcomes and complications for the trabeculectomy group were not as good as expected.

Beyond IOP control: optimising blebs
Bleb morphology needs to be optimized: it has long term implications for surgical success and complications such as blebitis and bleb-related endophthalmitis. Diffuse blebs are desirable without significant avascular areas (Figure 6); surgical technique\(^\text{4}\) as well as antimetabolites influence bleb outcomes. Modern bleb grading systems for clinical studies, such as the Moorfields Bleb Grading System\(^\text{27-29}\) (at www.blebs.net) provide clinical clues to bleb complications and failure\(^\text{18}\) that older grading systems can’t capture. Microstructural imaging of the bleb using confocal or OCT technology is possible\(^\text{21-31}\); it may prove useful in the future when we understand better the images produced.

Non-penetrating surgery
Non-penetrating glaucoma surgery (NPBS) drains aqueous through a trabeculodescemetec window rather than a sclerostomy, preferably without a bleb. Providing flow resistance, this window is created by unroofing Schlemm’s canal, but leaving inner tissue intact. An intrascleral “lake” sources aqueous variably to the suprachoroidal space, back into
the cut ends of Schlemm's canal, or into intra-scleral lymphatics. There are many variations, sometimes with stents.

NGPS may have decreased complication rates, but with diminished IOP-lowering effect compared with trabeculectomy. YAG laser gonipuncture may be needed to create a sclerotomy. Mitomycin is increasingly used, and blebs are associated with better IOP control\(^3\) (while intrascleral lake sizes may not be\(^3\)). There is a steep learning curve, and low IOPs early after surgery lead to better outcomes\(^4\).

Conclusion

In the last ten years trabeculectomy success and complication rates have improved significantly, not as a result of redesigning the procedure but from attention to detail, avoiding hypotony, managing wound healing, and a deeper understanding of the functional components of this form of glaucoma filtering surgery. Remaining challenges include unpredictable wound healing responses and, despite 5FU and MMC, suboptimal tools for modulating the wound healing response.

References